E/CONF.39/A/12
26 Sept.1962
ORIGINAL : ENGLISH

UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: A.4.2.5

Ceylon

SOLAR ENERGY FOR REFRIGERATION USING FLAT PLATE COLLECTORS

By J.C. CHINNAPPA, Ph.D., A.M.I. Mech. E.
Lecturer in Mechanical Engineering,
University of Ceylon, Colombo

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

NOTES

1. Papers selected for inclusion in General Sessions will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

2. Papers selected for inclusion in Specialized Sessions will be available at the Conference in only one of the above official languages.

3. Summaries of all papers, as submitted by contributors, will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

4. Papers and summaries will not be available for general distribution in advance of the Conference. They will be published in advance in limited quantities only for the use of delegations of participating governments and of other authorized participants. Post-Conference publication and general distribution of the Conference Proceedings will follow United Nations practices as laid down by the United Nations Publications Board.

SOLAR ENERGY FOR REFRIGERATION USING FLAT PLATE COLLECTORS

by
J.C.V.Chinnappa, Ph.D.,A.M.I.Mech.E.,
Lecturer in Mechanical Engineering, University of Ceylon,Colombo.

Introduction

1. In recent years there has been an increasing interest in the use of solar energy for providing cooling by operation of the vapour absorption refrigeration cycle. The intermittent cycle would seem to have engaged more attention[1,2,3,4,5,6] than the continuous cycle[7]. This paper attempts to evaluate the performance of commercial size units on the basis of the performance of an experimental intermittent refrigerator incorporating a flat plate collector.(The performance of the refrigerator will only be summarised here as a fuller report appears elsewhere[6].)

Experimental refrigerator and test results.

2. A simple experimental refrigerator made up of materials available locally was erected to operate on the intermittent cycle with solar energy as its only source of power, and is shown schematically in figure I. Circulation was by thermosyphon, assisted by bubble formation in the collector during regeneration. During regeneration valves VA and VB were open and valves VC and VD closed, thereby bypassing the absorber. During absorption valves VC and VD were open, and the ther two valves closed.

3. The solar energy collector consisted of a copper sheet 5 ft by 3 ft 6 in, and 0.03 in thick, painted dull black. To the plate were soldered six 1/4 in diam pipes at 6 in intervals. The ends of the 1/4 in pipes were welded into the headers. At the rear of the plate was corkboard insulation 4 in thick. There were 3 glass covers (1/8 in thick, and of commercial quality) in front of the collecting surface. The collector was inclined 24° facing due west. Figure II is a photograph of the rig.

4. The results obtained for 4 days are summarised in table 1. The 4 days were cloudless or nearly so. Regeneration took place during the hours of sunshine. Refrigeration was commenced when the solution had cooled to atmospheric temperature. During refrigeration the evaporator temperature gradually rose from the minimum value given in row 18 to about 27 °F at the end of refrigeration.

5. If a heat exchanger is provided to transfer heat from weak solution to incoming strong solution, the ratio of effective cooling to radiation received (row 23) can be increased to about 8 or 9 per cent, and the effective cooling per ft^2 of collector surface would also show a corresponding improvement - i.e. 100 btu/sq ft would be a reasonable expectation for effective cooling on a cloudless day.

Applications of the intermittent and continuous cycles.

6. Two categories may be specified: (a) applications where cooling is not required during the period of regeneration, and (b) applications where cooling is required during the period of regeneration.

7. The intermittent cycle may be considered for applications in the first category. Two examples are ice manufacture and the cooling of residential rooms at night. Test results indicate that for an iceplant using aqua-ammonia with a refrigeration capacity of 1 ton(heat abstraction of 288 000 btu per day though not continuously), about 3000 sq ft of collecting surface would be required, and prevision made in the plant for the storage of about 5000 lb of strong solution(compare row 24, table 1), and 525 lb of refrigerant.

8. For the airconditioning application the initial solution concentrations may be higher with a consequent improvement in the cycle COP. Hence for a similar refrigeration capacity of 1 ton, the area of the collecting surface and solution storage capacity would be about half that required for ice manufacture.

9. In these applications the size of the storage vessels will militate against the development of large units unless higher generator temperatures are realised by auxiliary concentrating solar collectors or fossil fuel combustion.

10. In the second category of applications - i.e. when cooling is required during the period of regeneration -- it is necessary for regeneration and absorption to proceed simultaneously. Therefore if the intermittent cycle is employed provision must be made for twice the solution storage required for an application in the first category. It seems that the continuous cycle would be more suitable here.

11. In a continuous cycle application using aqua-ammonia, a successful hermetically sealed circuit has been designed incorporating an electrically operated transfer tank to transfer solution from the absorber to the generator[8]. The use of electrical power may be avoided by providing solution reservoirs and valves to be operated manually, or better, if such can be successfully devised, a float - operated transfer tank[9].

12. For ice manufacture a 3-stage continuous cycle cascade system may be considered. This arrangement is not entirely impractical as it may be more convenient to construct the generator in 3 units since the generator heating surface(the solar collector) is so extensive. This scheme would appear to merit further investigation.

13. the continuous cycle may be also considered for room cooling, and the design of such a unit is outlined below.

Design of solar energy operated room cooler.

14. The operating conditions for the aqua-ammonia cycle were chosen as follows: strong solution leaving absorber - concentration 0.59, temperature 100 °F; weak solution leaving generator - concentration 0.495, temperature 170 °F condenser pressure 200 lbf/sq in. Assuming a thermal ratio of 0.5 for the heat exchanger in the solution circuit, the COP is obtained as 0.58.

15. The load is the cooling of an office room from 8 a.m. to 4 p.m. at the rate of 18 000 btu/h. The expected evaporator temperature is about 56 °F and

the room is to be cooled by panels in which the refrigerant evaporates. It has been estimated that 600 sq ft of collecting surface (with 2 glass covers) would be required to provide the necessary solar heat for the generator. Solution and refrigerant storage will also be incorporated so that the cooling period could over-run the regeneration period by about an hour when so required.

Conclusion

16. Even when electrical power or fossil fuel combustion makes high generator temperatures possible, the absorption refrigerator is larger than its vapour compression counter part, and its first cost is greater[9]. With solar regeneration using flat plate collectors, the absorption refrigerator becomes even bulkier - and more expensive. However, a comparison of the first costs, maintenance costs, depreciation and running costs of a solar operated refrigerator and a vapour compression unit would be interesting, particularly in a region where fossil fuels are imported and electrical power is relatively expensive.

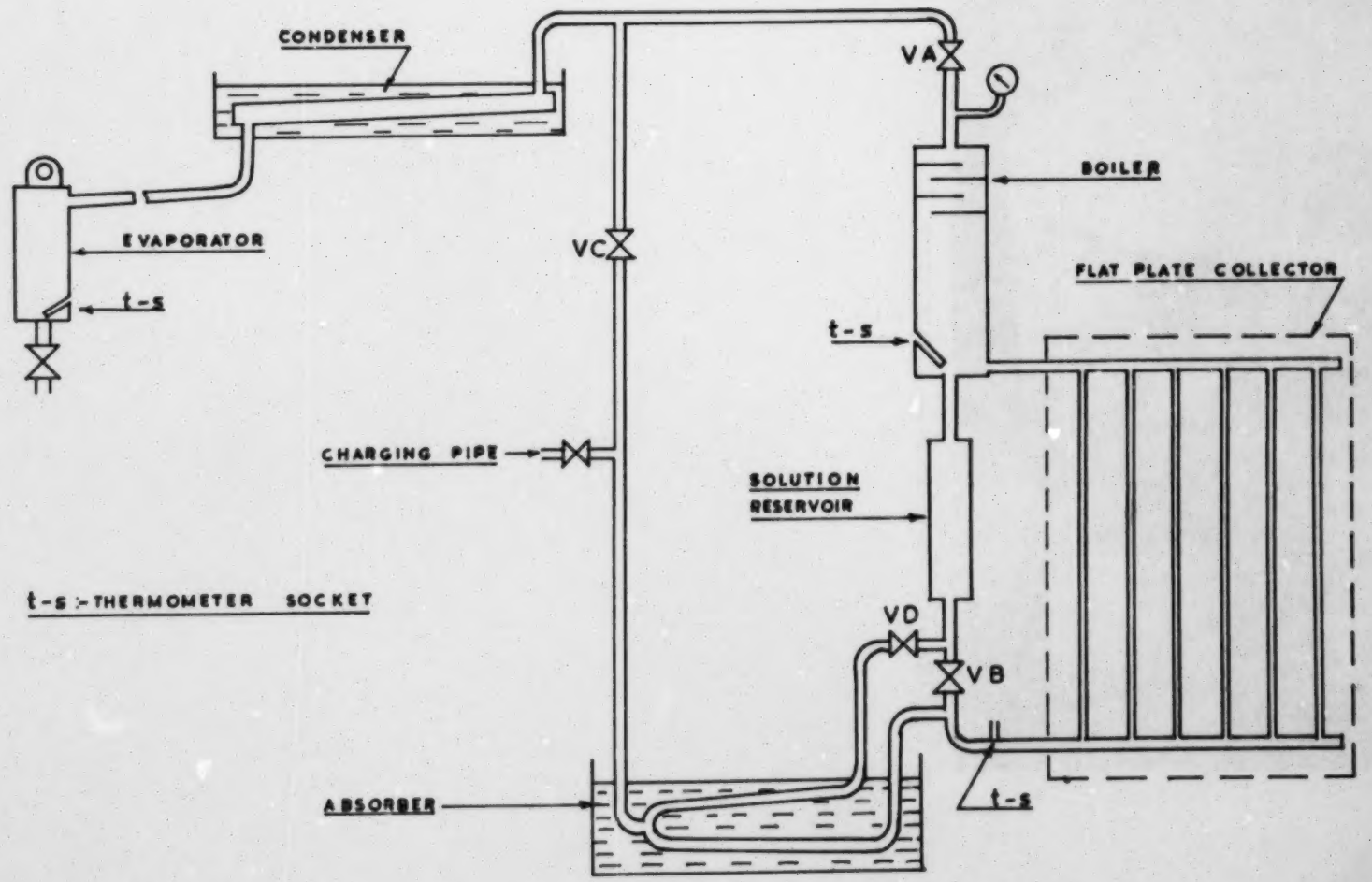
References

1. Williams,D.A. Chung,R.,Lof,G.O.G., Fester,D.A.,and Duffie,J.A. Intermittent Absorption Cooling Systems with Solar Regeneration Paper no. 57-A-60, A.S.M.E.
2. Williams,D.A.,Chung,R.,Lof,G.O.G.,Fester,D.A.,and Duffie,J.A. Cooling Systems based on Solar Regeneration Refrig.Eng. 33,(Nov 1958)
3. Eisenstadt,M.M.,Planigan,F.M.,and Farber,E.A. Solar Air-Coditioning with an Ammonia-Water Absorption Refrigeration SystemPaper no. 59-A-276,A.S.M.E.
4. Trombe,F., and Foex,M. The Production of cold by means of Solar Radiation Solar Energy, 1, no.1,51(1957).
5. Chinnappa,J.C.V. Experimental Study of the Intermittent Vapour Absorption Refrigeration Cycle using the Refrigerant-Absorbent Systems of Ammonia-water and Ammonia-Lithium Nitrate Solar Energy 5, 1(1961)
6. Chinnappa,J.C.V. Performance of an Intermittent Refrigerator operated by a Flat Plate Collector, Solar Energy, 6, no.4 (1962)
7. Baum,V.A. Prospects for the Application of Solar Energy and some Research Results in the U.S.S.R. Proc Solar Energy Symp. Phoenix, 297,(1955).
8. Merrick.R.H.and English,R.A. An Air-Cooled Absorption Cycle Trans, A.S.H.R.A.E., 166 339 -347,(1960)
9. Ellington,R.T.,Kunst,G,Peck,R.E. and Reed,J.F. The Absorption Cooling Process Inst.of Gas Tech.,Res.Bull.14 (1957)

TABLE 1. Summary of Solar Refrigerator Test Results

1. Test no.	9	12	13	14
2. Date of commencement of test	13 Feb	3 Mar	6 Mar	9 Mar 1960
REGENERATION				
3. Time of starting a.m.	9-45	9-41	10-25	10-50
4. Duration	5 h	6 h 40min	5h 5 min	5h 30min
5. Initial mass of solution,lb	17.97	19.61	18.76	19.47
6. Initial temp. of solution, F	83	86	89	89
7. Initial conc.(mass fraction NH_3)	0.462	0.464	0.44	0.460
8. Maximum solution temp. °F	202.5	212	211.5	211
9. Maximum solution press. lbf/sq in	207	205	203	205
10. Final concentration	0.398	0.370	0.364	0.377
11. Mass of distillate(NH_3) lb	1.92	2.92	2.24	2.59
12. Condenser cooling water temp.°F	86-96.5	86.5-96.5	87-94.5	87-95.3
13. Atmospheric temperature °F	87-95	88-90	88-90	88-90
14. Heat received by solution and distillate(Q_s) btu	3786	4869	4220	4533
15. Total radiation received(Q_r)btu	16 671	23 576	18 900	20 022
REFRIGERATION				
16. Approximate duration h	3	6	5	5
17. Absorbing solution temp. °F	93-95	91.5-95	95-97.5	94-99
18. Minimum evaporator temp. °F	14.5	9.5	8	13
19. Total effective cooling btu	900	1360	1052	1217
20. Effective cooling per sq ft of collecting surface per day	51.4	77.8	60.2	69.5
21. Actál COP	0.238	0.279	0.249	0.268
22. Theoretical COP	0.30	0.316	0.267	0.302
23. Ratio of total effective cooling to total incident radiation %	5.4	5.8	5.6	6.0
24. Effective cooling produced per lb of strong solution btu/lb	50.1	69.4	56.1	62.5
PERCENTAGE ENERGY BALANCE DURING REGENERATION				
25. Total incident radiation (Q_r)	100	100	100	100
26. Radiation incident on collector plate (Q_{rp})	60.5	58.5	59	62
27. Increase in heat content of solution(both phases)(Q_{sh})	22	20	22.5	21.5
28. Heat absorbed by collector, solution circuit, insulation(Q_e)	15	11.5	13.5	12.5
29. Heat loss from collector plate, and solution circuit(Q_l)	23.5	27	23	28

FIGURE I SCHEMATIC DIAGRAM OF EXPERIMENTAL REFRIGERATOR



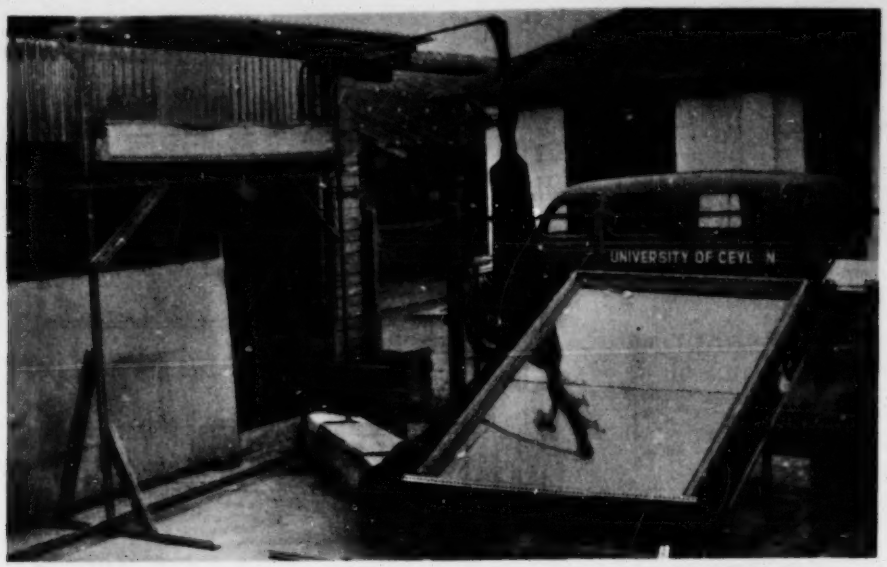


Fig. II Experimental Intermittent Refrigerator

44 E - Sept.1962 - 1,600